Proposed Photovoltaic Module Form Factor to Reduce Levelized Cost of Energy

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***Abstract* — This paper discusses a proposed photovoltaic (PV) module form factor designed for utility-scale, one-axis tracking projects. The purpose of the form factor is to: 1) reduce total installed costs for utility-scale projects; 2) improve module reliability; 3) reduce operating and maintenance (O&M) costs, and (4) improve the project return on investment.**

The proposed module uses a double-glass construction to improve reliability and service lifetime in a form factor that is longer and narrower than existing 60-cell modules. This form factor places more module area per linear meter of torque tube when used with single-axis trackers. These changes are expected to lower the levelized cost of energy.

***Index Terms* — module, form factor, installation cost reduction, operation and maintenance (O&M), module manufacturing.**

I. Introduction

This paper discusses a proposed photovoltaic (PV) module form factor for high-wattage cells and double glass construction.

The primary aim of the form factor is to reduce the levelized cost of energy by designing the module to: 1) improve module reliability, 2) reduce construction costs, 3) reduce operation and maintenance (O&M) costs, and 4) improve lifetime project return on investment. These benefits may come at the price of higher module manufacturing costs.

Currently, a widely used form factor for 1-axis tracking projects is a 72-cell module with a glass-cell-backsheet composition. As the industry strives to make improvements to the existing 72-cell modules, three issues should be considered:

1) A72-cell module with a glass-cell-glass configuration would likely weigh more than 51 pounds (23.13 kilograms), the Operational Safety and Health Administration’s (OSHA’s) maximum allowable weight limit for handling the module with two hands under ideal conditions.

2) As cell efficiencies improve, in the near future it is likely that cells could reach 4.85 watts of power each; a 72-cell module would be capable of generating 349 watts of power. Under certain sunlight and shading conditions, this may result in a hot spot exceeding the EVA curing point [1]-[4]. For example, under full sun light conditions with partial shading, each string pair would generate 116 watts of power. If this power were dissipated in a micro crack, or partially shaded cell, this would likely result in a hot spot with temperatures greater than 120 °C, which could result in encapsulant degradation.

3) Module wiring is seen as an activity that causes a lot of man-hours in the field to complete. Modules should have an integrated wire management plan to reduce field labor. [5]

For these reasons, a new form factor is needed in 2015 to prepare for high-wattage, glass-cell-glass modules. Figure 1 compares a proposed 56-cell module with today’s industry standard sizes of 60-cell and 72-cell form factors.

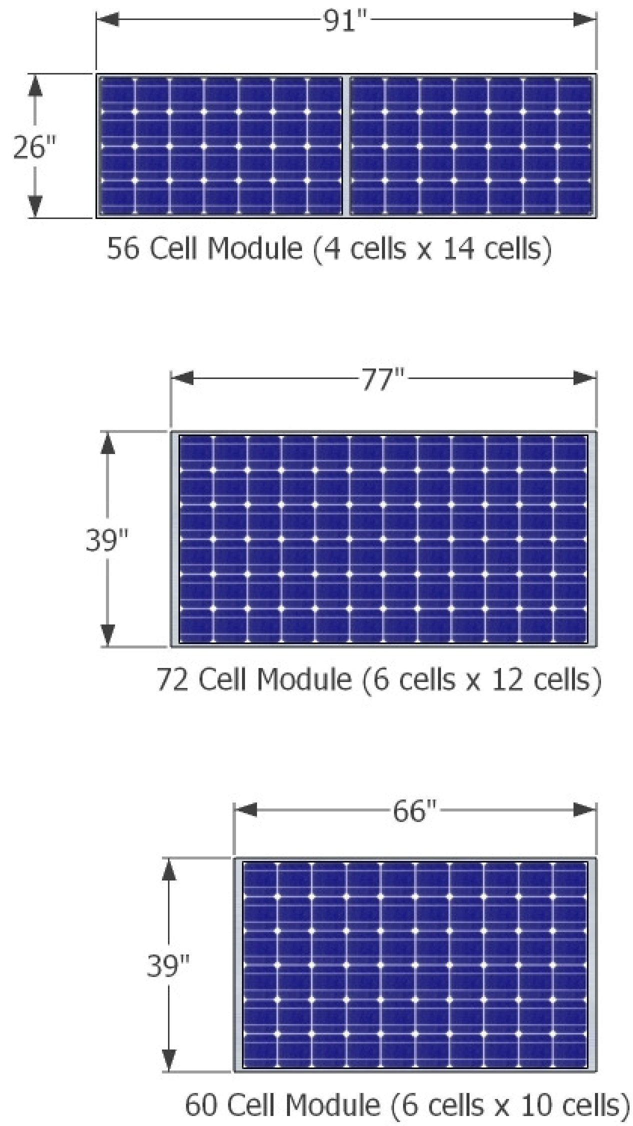

Fig. 1. Standard 60-cell and 72-cell modules compared with the proposed 56-cell module.

II. Design Guidelines for the Proposed Module Form Factor

The following constraints/design guidelines for the proposed module form factor were developed by CH2M HILL across a team of manufacturing engineering, construction ergonomics, industrial engineering, cost estimating, and solar PV engineering staff.

A. Form Factor Design Guidelines

1) Module Manufacturing
- Cell and string pair wiring should be compatible with existing cell manufacturing equipment

2) Module Reliability
- Double glass construction
  - Reduces water ingress
  - Lowers mechanical stress (as the cell is in the center of the module bending line)
  - Reduces backsheet scratches during construction (glass is mechanically stronger than typical backsheet materials)
- Fewer cells per bypass diode
  - Less than 80 watts per string to reduce hot spots (no more than 16 cells per string)[1]
  - Less than 13.5 volts per string to prevent breakdown of PV junction (no more than 21 cells per string)
- Integrated frame designed for module stability and tracker mounting

3) Ergonomics and Construction
- Modules should weigh less than 51 pounds [lb] (23.1 kilograms [kg]) to allow 1-person lifting ergonomics[2]
- Torque tube height should be less than 44 inches [in] (1.07 meters [m]) for installation ergonomics
- Dual junction boxes to reduce module wiring and tie wrapping of wires in the field

4) Operations and Maintenance
- Single-axis tracker able to tilt to 42° with the bottom of the module at least 12 inches (0.30 meter) above grade for vegetation clearance

TABLE 1

Design Constraints and Guidelines for the Proposed Form Factor

Module Form Factor		**Module Manufacturing**		**Module Reliability**		**Ergonomics and Construction**		**O&M**
Module Configuration (# of cells)	Cell width and height	Ease of manufacturing	Number of bypass diodes	Watts per string pair (assuming 4.85 watts/cell) <80 watts desired for reliability >100 watts not recommended	Voltage of string pair <13.5 volts desired for reliability	Estimated weight using double glass construction - less than 51 lb. (23.1 kg) required, less than 49 lb (22.2 kg) desired	Height of module on tracker tube at 0° rotation (less than 44 in (1.2 m) desirable for construction ergonomics)	O&M row spacing (in feet) > 12.6 feet (3.84 m) for pickup truck access (truck + 2 feet (0.6 m) either side for access)
60	6 x 10	**Excellent**	3	97	**12.2**	**46**	**35.2**	11
72	6 x 12	**Excellent**	3	116	14.6	55	**39.6**	**13**
65	5 x 13	Poor	5	**63**	**7.9**	50	**41.8**	**14**
70	5 x 14	Poor	5	**68**	**8.5**	54	**44.0**	**15**
75	5 x 15	Poor	5	**73**	**9.2**	58	46.2	**16**
80	5 x 16	Poor	5	**78**	**9.8**	61	48.4	**17**
85	5 x 17	Poor	5	82	**10.4**	65	50.6	**18**
90	5 x 18	Poor	5	87	**11.0**	69	52.8	**19**
72	4 x 18	Good	4	87	**11.0**	55	52.8	**19**
68	4 x 17	Good	4	82	**10.4**	52	50.6	**18**
64	4 x 16	Good	4	**78**	**9.8**	49	48.4	**17**
60	4 x 15	Good	4	**73**	**9.2**	**46**	46.2	**16**
56	4 x 14	Good	4	**68**	**8.5**	**43**	**44.0**	**15**

*Highlighted text indicates desirable module properties

III. Highlights of the Proposed Module Form Factor

The proposed 56-cell module improves on the existing modules in several ways. Figure 2 shows the cell configuration.

1) Double glass construction enables improved reliability and reduced degradation
2) Having fewer cells per bypass diode protects modules from hot-spot issues
3) Increased length reduces installation labor costs for tracking projects
4) Dual combiner boxes to reduce installation labor and the number of tie wraps
5) A module with a fewer number of cells reduces overall module weight

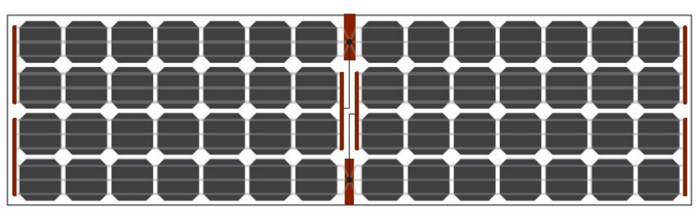

Fig. 2. Cell configuration of 56-cell module.

[1] Assumes a 2 year-ahead cell output of 4.85 watts per cell (290 watts for a 60-cell module).

[2] Double-glass construction is assumed to be slightly heavier as twin 2 millimeter panes of glass (or 2.5 millimeter front glass) would contain more glass than a single 3.2 millimeter pane of glass for glass-cell-backsheet modules. For this paper, an estimate of 0.767 pounds per cell (0.348 kilograms per cell) is used to determine module weight.

IV. Installed Cost Comparison with Current Module Form Factors

TABLE 2
INSTALLATION COSTS FOR UTILITY-SCALE PV PROJECTS FOR VARIOUS MODULE TYPES

	60-cell glass-cell-glass	72-cell glass-cell-backsheet	56-cell glass-cell-glass	Comment
Module Installation (uncrate, stage, mechanical install, trash removal)	1.19	1.0	1.25	
Module Installation (electrical installation)	1.14	1.0	1.06	Includes wire harness, tie wraps
DC Wire (material and installation)	1.05	1.0	.85	
Support Posts (material and installation)	1.11	1.0	.82	From combiner to inverter
Trackers (material and installation)	1.10	1.0	1.0	Includes motors
BOP (material and installation)	1.01	1.0	1.01	All other items not listed above
Construction Indirects	1.03	1.0	1.0	
EPC Mark Ups	1.07	1.0	.99	
Total Non-Module Cost Factor	1.07	1.0	.99	

From the data in table 2, comparing prices on a unit basis, the baseline 72-cell module is 1.0, 60-cell (glass-cell-glass) is 1.07, and the proposed 56-cell module is a 0.99. For example, if a project installed costs (module cost excluded) were \$100 million with 72-cell modules, CH2M HILL estimates installation and BOP costs would be \$107 million with 60-cell glass-cell-glass modules, and \$99 million with the proposed 56-cell module. The cost savings for the proposed 56-cell module come from savings with the posts and tracker as the longer module requires fewer posts and fewer tracker gears to achieve 1 MW.

V. Operations and Maintenance Comparison with Current Module Form Factors

Module size creates a row-to-row spacing that accommodates a standard bobtail water truck for O&M washing, based on a 33 percent ground coverage ratio for 1-axis tracking (see Figure 3). This will allow for quicker and less expensive cleanings.

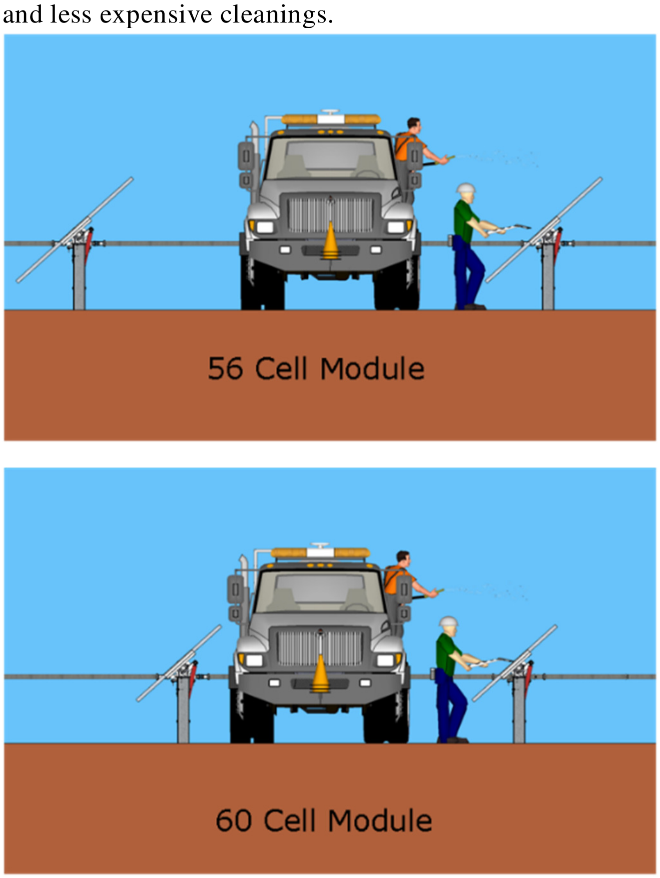

Fig. 3. Module cleaning of 56-cell modules using a water truck (row spacing based on 33 percent ground coverage ratios).

VI. Levelized Cost of Energy Comparison with Current Module Form Factors

The levelized cost of energy (LCOE) for the proposed 56-cell module is compared with a 60-cell double glass module and a 72-cell glass-cell-backsheet module.

For purposes of comparison, Solar World's 60-cell module warranty was used as the quantification basis for comparison (86.85% at year 30 year versus 80% at year 25 for glass-cell-backsheet modules). [6]

The financial analysis uses the System Advisor Model (SAM) model with the following assumptions: 1) Tonopah, Nevada Typical Meteorological Year weather data; 2) SAM production estimates for a 255 MW_{DC} facility using 1-axis tracking; 3) Cost of debt 7%; 4) 50% debt financed; 5) Discount rate 8.2%; 6) PPA price of \$0.06, escalated at a 1%/yr rate; 7) O&M = \$17.25/kW_{DC}/year for 56 and 72-cell module cases, \$17.5/kW_{DC} for the 60-cell case as washing is estimated to be slightly more expensive, 8) insurance rates 0.50 % of installed costs {SAM default}; 9) Glass-cell-backsheet module output equals module warranty (97% year 1, 0.7%/year degradation to year 25); 10) Double glass module output equals module warranty (97% year 1, 0.35%/year degradation to year 30); 11) Year 1 outputs would be the same (same ground coverage ratio in design); 12) Assume tax benefits and depreciation benefits at a tax rate of 34%; 13) NV sales tax at 2.5%; and 14) time of use rates with peak summer factors of 2.066 and 1.44 (from NV Energy).

Additional assumptions for each case are included in Table 3. Assumptions such as module cost, degradation, O&M, and module life expectancy are different for each module type.

Table 3 shows the summary of the comparison; the Internal Return on Investment is ~0.5% higher with the proposed 56-cell module, even with a higher module cost.

TABLE 3
LEVELIZED COSTS FOR UTILITY-SCALE PV PROJECTS FOR VARIOUS MODULE TYPES

	60-cell	72-cell	56-cell
Module construction	Glass-cell-glass	Glass-cell-backsheet	Glass-cell-glass
Module life expectancy	30 years	25 years	30 years
Degradation (%/year)	0.35	0.7	0.35
Module costs ($/W$_{DC}$)	0.69	0.65	(Estimated) 0.69
BOP costs ($/W$_{DC}$)	1.31	1.24	1.23
Indirect Costs ($/W$_{DC}$)	0.11	0.10	0.11
Installed costs ($/W$_{DC}$)	2.11	1.99	2.03
O&M + washing ($/kW$_{DC}$/yr)	17.5	17.25	17.25
Insurance costs (% of capital costs)	0.5	0.5	0.5
PPA ($/kWh)	0.06	0.06	0.06
IRR	16.2	16.8	17.3

VII. SUMMARY

A change in module form factor for the age of high wattage, double glass modules could improve the cost of electricity for solar projects. A proposed 56-cell double glass module in a 4-wide by 14-high cell orientation could lower capital costs, improve module reliability, and improve levelized cost of energy. Based on the economic analysis shown in Table 3, a 56-cell module could cost up to $0.04/W$_{DC}$ more than a standard 72-cell module and achieve a slightly better investor return (17.3% versus 16.8% for a standard 72-cell module).

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